Knight: Chapter 17

Work, Heat, & the 1^{st} Law of Thermodynamics

(*The Specific Heat of Gases*)

Last time…

- *Heat* needed to change temp by ΔT (*only* when W=0!) is..

$$\boxed{Q = Mc\Delta T}$$

Specific heat

or

$$\boxed{Q = nC\Delta T}$$

Molar specific heat

- *Heat* needed for a phase change…

$$\boxed{Q = \pm M L_{f,v}}$$

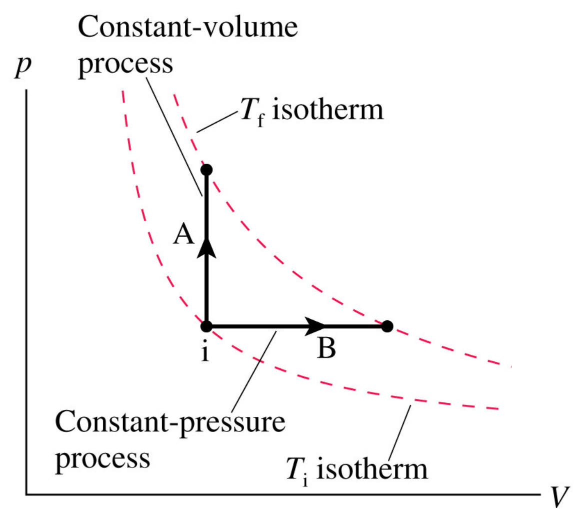
- Calorimetry…

$$\boxed{Q_{net} = 0}$$

The Specific Heat of Gases

Consider the two processes A & B...

- Both have the *same* ΔT, therefore the *same* ΔE_{th}, but they require *different* amounts of Q.
  - The reason is that work is done in process B but not in process A.
- The total change in thermal energy for any process, due to work and heat, is:



$$\boxed{\Delta E_{th} = nC_V \Delta T} \quad \text{(any ideal-gas process)}$$

$\Delta E_{th} = nC_V\Delta T = W + Q$

The Specific Heat of Gases

Define 2 different versions of the specific heat of gases…

- one for constant-*volume* processes.
- one for constant-*pressure* processes.

- The quantity of heat needed to change the temperature of *n* moles of gas by ΔT is:

$$\boxed{\begin{aligned} Q &= nC_V\Delta T \\ Q &= nC_P\Delta T \end{aligned}} \quad \begin{aligned} &\text{(temp change at constant volume)} \\ &\text{(temp change at constant pressure)} \end{aligned}$$

- where C_V is the *molar specific heat at constant volume* & C_P is the *molar specific heat at constant pressure*.

Constant volume : $W = 0 \therefore Q = nC_V\Delta T$ (no area under PV curve)

Constant pressure : $W \neq 0 \therefore Q = nC_P\Delta T$

The Specific Heat of Gases

What if neither the pressure nor the volume is constant?

The Specific Heat of Gases

What if neither the pressure nor the volume is constant?

- no direct way to relate Q to ΔT!
- Use the 1st law of thermodynamics:

$$Q = \Delta E_{th} - W$$

Extra credit problem

i.e. 17.8: Calorimetry with a gas and a solid

The interior volume of a 200 g hollow aluminum box is 800 cm^3. The box contains nitrogen gas at STP. A 20 cm^3 block of copper at a temperature of 300° C is placed inside the box, then the box is sealed.

What is the final temperature?

$$\Delta E_{th} = \underbrace{nC_v\Delta T}_{\text{gas}} = Q + \cancel{W} \quad \text{no work}$$

$$Q = nC_v\Delta T$$

$m_{AL} = 0.2$ kg

$V_{N_2} = 800\ cm^3 = 8.0\times10^{-4}\ m^3$

$T_{0AL} = T_{0N_2} = 273K$ (+Q) gains heat

$P_{N_2} = 1.01\times10^5$ Pa

$V_{cp} = 20\ cm^3 = 2.0\times10^{-5}\ m^3$

$T_{0cp} = 573K$ (-Q) loses heat

$c_{AL} = 900$ J/kgK

$c_{cu} = 385$ J/kgK

$C_v = 20.8$ J/mol kg

$\rho_{cu} = \frac{M_{cu}}{V_{cu}}$

$M_{cu} = (8920\ kg/m^3)(2.0\times10^{-5}\ m^3)$

$M_{cu} = 0.178$ kg

$$n_N = \frac{PV}{RT} = \frac{(1.01\times10^5\ Pa)(8.0\times10^{-4}\ m^3)}{(8.31\ J/mol\,K)(273\ K)} = 3.53\times10^{-2}\ mol$$

$$Q_{cu} + Q_{AL} + Q_{N_2} = 0$$

$$M_{cu}c_{cu}(T_1 - T_{0cu}) + M_{AL}c_{AL}(T_1 - T_{0cu}) + nC_v(T_1 - T_{0N_2}) = 0$$

$$(M_{cu}c_{cu} + M_{AL}c_{AL} + nC_v)T_1 = M_{cu}c_{cu}T_{0cu} + M_{AL}c_{AL}T_{0AL} + nC_vT_{0N_2}$$

$$T_1 = \frac{M_{cu}c_{cu}T_{0cu} + M_{AL}c_{AL}T_{0AL} + nC_vT_{0N_2}}{(M_{cu}c_{cu} + M_{AL}c_{AL} + nC_v)}$$

$T_1 = 356$ K

C_P and C_V

Consider Table 17.4…

TABLE 17.4 Molar specific heats of gases (J/mol K)

Gas	C_P	C_V	$C_P - C_V$
Monatomic Gases			
He	20.8	12.5	8.3
Ne	20.8	12.5	8.3
Ar	20.8	12.5	8.3
Diatomic Gases			
H_2	28.7	20.4	8.3
N_2	29.1	20.8	8.3
O_2	29.2	20.9	8.3

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Notice:

- *Molar specific heats* of *monatomic* gases are *all alike.*
- *Molar specific heats* of *diatomic* gases are *very nearly alike.*
- The *difference* is the *same* in every case &...

$$\boxed{C_p - C_V = R}$$

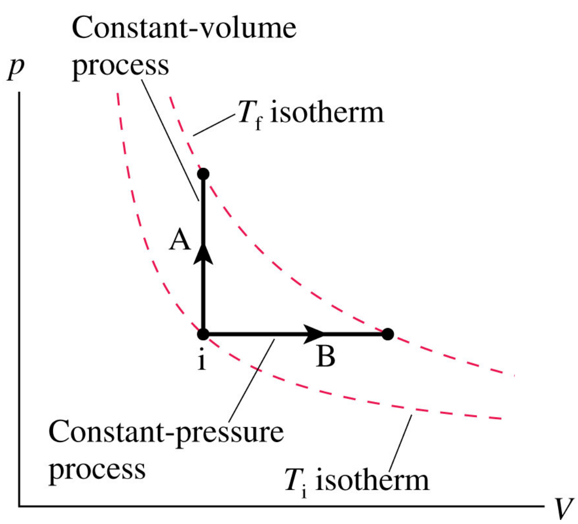
Coincidences?

C_P and C_V

The change in thermal energy of the gas is the *same* for any two processes that have the same ΔT.

$$\boxed{\Delta E_{th} = nC_V \Delta T}$$

Consider Figure 17.20…



Q: Which process requires *more heat* to produce the same ΔT?

Path A

$W = 0 \quad \therefore \quad \Delta E_{th} = nC_V \Delta T = Q_A$

$\Delta E_{th_B} = nC_V \Delta T = W + Q = -nR\Delta T + nC_p \Delta T \quad \therefore \quad C_V = -R + C_p$

$nC_V \Delta T = -p\Delta V + Q \qquad R = C_p - C_V$

$\Delta pV = \Delta(nRT)$

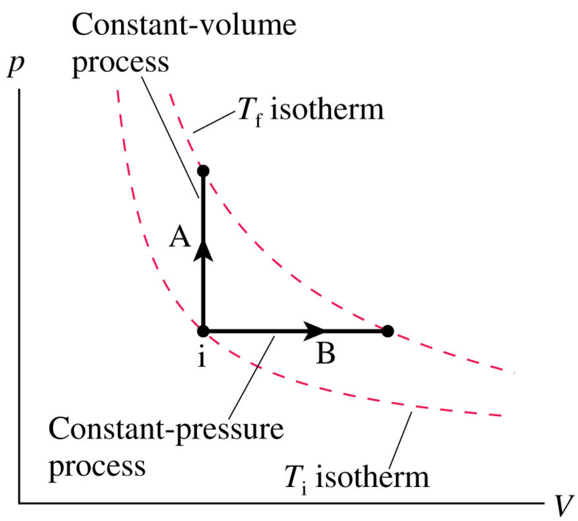
$p\Delta V = nR\Delta T$

C_P and C_V

The change in thermal energy of the gas is the *same* for any two processes that have the same ΔT.

$$\boxed{\Delta E_{th} = nC_V \Delta T}$$

Consider Figure 17.20…



$$\boxed{C_P = C_V + R}$$

The *heat* required to bring about a temperature change depends on what the process is.

Quiz Question 1

1 mol of air has an initial temperature of 20°C. 200 J of heat energy are transferred to the air in an isochoric process, then 200 J are removed in an isobaric process. Afterward, the air temperature is

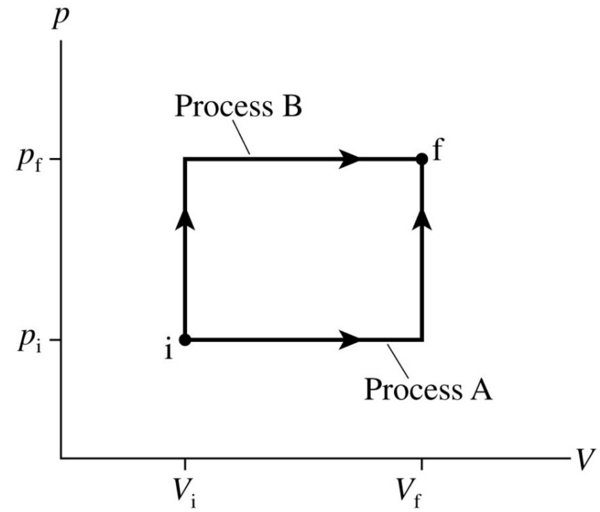
$C_p = C_v + R$

$Q = nC_p\Delta T_p$ isobaric
$Q = nC_v\Delta T_v$ isochoric

1. < 20°C.
2. = 20°C.
3. > 20°C.
4. Not enough information is given to answer the question.

Heat depends on the path..

Consider the two ideal-gas processes…



- There's more area under the process B curve, so $|W_B| > |W_A|$.
- $W < 0$ as the gas *expands*.
- ΔE_{th} is the *same* for both processes, so $W_A + Q_A = W_B + Q_B$.
- Only true if $Q_B > Q_A$.

Heat *added* or *removed* during an ideal-gas process depends on the path followed through the pV diagram!

Adiabatic processes…

2 ways one can have an adiabatic process..

Gas cylinder can be…

1. completely surrounded by *thermal insulation*.
2. *expanded* or *compressed* very rapidly where there is no time for heat to be transferred between the gas and the environment.

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Notice:

- *Adiabatic expansions* or *compressions* are…
  - *fast enough* to be *adiabatic*, but *slow enough* to still be considered *quasi-static*.
- For an adiabatic process, $Q = 0$ so $\Delta E_{\text{th}} = W = nC_V\Delta T$
  - Adiabatic compression (expansion) raises (lowers) the temp of a gas.

Adiabatic processes…

An *adiabatic process* is one for which…

Adiabatic processes…

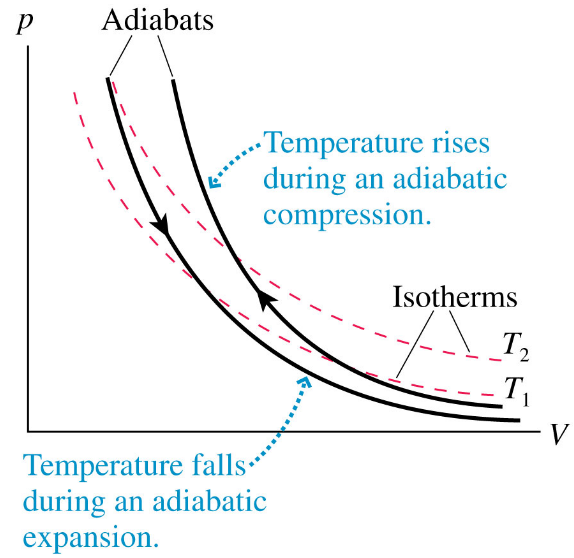
An *adiabatic process* is one for which…

$$\boxed{pV^{\gamma} = \text{constant}}$$

where

$$\gamma = \frac{C_P}{C_V} = 1.67 \quad \text{monatomic gas}$$

$$= 1.40 \quad \text{diatomic gas}$$



Adiabats are steeper than hyperbolic isotherms, so the temp

- *falls* during an *adiabatic expansion*
- *rises* during an *adiabatic compression*.